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Oceanographic analysis of sun glint images taken on space shuttle mission STS 41-G

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NAVAL POSTGRADUATE SCHOOL
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OCEANOGRAPHIC ANALYSIS OF SUN GLINT IMAGES
TAKEN ON SPACE SHUTTLE MISSION STS 41-G

by

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March 1986

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Oceanographic Analysis of Sun Glint Images Taken on Space Shuttle Mission STS 41-G

by

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Lieutenant, United States Navy
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ABSTRACT

A series of four sun glint images taken by the crew of the space shuttle Challenger, mission STS 41-G, on 8 October 1984 were analyzed and compared to NOAA-7 AVHRR infrared images and to bathythermographs of the same area. Evidence of the Almaria Front, a persistant oceanographic feature east of the Alboran Basin, was found on all three data sets, and the efficacy of using sun glint images for the location of acoustically important oceanographic features was supported. A practical use of sun glint photographs taken from low earth orbit was demonstrated and the investigation of its use to help in the employment of acoustic sensors is further justified by this work.

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I. INTRODUCTION

In October 1984 the space shuttle Challenger (Mission STS 41-G) carried for the first time a dedicated Navy oceanographer, Paul Scully-Power, into space. His task among others was to more fully explore the potentials of manned, orbital remote sensing of the world's oceans. Although remote sensing either by unmanned satellite or manned vehicles has been conducted quite vigorously for almost two decades, this was the first time a professional oceanographer was afforded the opportunity to study, in real time, ocean processes from a space born platform. Since the observer was part of the remote sensing system he was able, within certain limitations, such as the shuttle's orbit, to determine which features to study.

An important aspect of the mission was the synergism which existed between the observer and the shuttle sensor system. Not only were photographic cameras and the Shuttle Imaging Radar (SIR-B) available to record features of interest but a highly trained human sensor system was as well. This afforded an unprecedented selectivity and correspondingly high quality and quantity of information to be gathered. Mr. Power's experience confirmed that a trained observer can integrate huge amounts of information while still maintaining the ability to discriminate extraordinary detail. For instance, under some conditions of flight geometry and solar illumination waves breaking on shorelines were clearly discernible [Ref. 1].

Among all the data retrieved from the mission, some of the most striking was the visible record of the sea surface under the condition of sun glint. This portion of the record, while not unique as a method for ocean study [Ref. 2] was new in that some features such as submesoscale fronts and eddies were found to be far more ubiquitous and interconnected than previously suspected [Ref. 3]. Of particular interest was the sun glint record obtained from the Mediterranean Sea. For most of the 7 day mission much of the Mediterranean was cloud free thus permitting a wonderful opportunity to see and record oceanographic processes in a detailed and chronological fashion.

During STS 41-G, a number of cooperative experiments were performed utilizing the shuttle and its capabilities along with simultaneous in situ data collection performed by earth bound scientists. Naval Ocean Research and Development Activity (NORDA) investigators Paul E. La Violette and Robert A. Arnone, who have extensively studied western Mediterranean oceanographic features [Ref. 4,5,6] conducted an experiment in and around the western Mediterranean's Alboran Gyre. Their work included accurately positioning patterns of air dropped expendable bathythermographic buoys (AXBT) over oceanographic features in the western Mediterranean. Additionally air and ship born observations were gathered to help characterize the complex flow and circulation of the Alboran Sea. The shuttle's role here consisted of complementing these ground truth or in situ measurements with a remotely sensed "picture" of this dynamic and important area.

A very interesting series of four sun glint images of the waters just to the south and east of Spain's Capo de Gata were taken on 8

October. They are particularly noteworthy for their clarity and the complexity of the features they contain. The various features resolved include ship wakes, submesoscale fronts and eddies, internal waves, frontal shearing, and sea state. The area resolved consists of an approximately 40 nautical mile (n.m.) swath starting at Capo de Gata and running 110 n.m. east southeast. This visible photographic record includes the Almaria Front, a feature of ongoing interest to La Violette and Arnone and now part of an extended study called the Western Mediterranean Circulation Experiment (WMCE) [Ref. 7].

The Almaria Front is a permanent, albeit variable, oceanographic feature of the area just as the Alboran Gyre is to the west. On 10 October 1984, La Violette and Arnone placed a pattern of 49 AXBTs in the vicinity of the Almaria Front and recorded subsurface temperature profiles which resulted in at least a partial characterization of the feature in three dimensions. The two records, that from STS 41-G and the AXBT temperature profiles present an interesting opportunity to examine the oceanography of the area. They are temporally separated by two days. However, correlation was still possible. The NOAA-7 AVHRR satellite infrared record spans the time period and its correlation with western Mediterranean circulation has been established [Ref. 4,5,6,8]. Some natural questions arise from reviewing the data such as; are the surface structures observed in the sun glint images correlated with underlying subsurface dynamics? And are the oceanographic features imaged acoustically significant?

At present the relationship between the highly detailed surface structure as seen in these sun glint pictures and the underlying

acoustical environment is unclear. Also a specific correlation study of infrared images taken from NOAA-7 with this sun glint record has not been performed. It is the intent of this paper to show that a correlation exists between the sun glint images taken on STS 41-G and the infrared images obtained from the NOAA-7 AVHRR. Furthermore, that sun glint images can infer acoustically important information which can ultimately be tactically useful.

II. WESTERN MEDITERRANEAN OCEANOGRAPHIC OVERVIEW

A. BATHYMETRY

This part of the Mediterranean is demarcated on the west by the Strait of Gibralter and in the east "by a line joining Capo de Gata, Spain (2° W), and Cape Fegato, Algeria (1° W)" [Ref. 8: p. A-3]. The major basin of the region is the Alboran Basin centered approximately at 36° North and 4° West, position A (see Fig. 1). A lesser basin north of Cape Tres Forcas is not as deep or large, position B. Separating the two is a system of ridges and banks, including the Isla de Alboran, position C, which lies in a southwest to northeast line. Both basins are marked by very steep coastal slopes. The submarine topography south of Capo de Gata consists of a rapidly descending slope which levels out to about 1000 fathoms until 36° North where a steep ascending slope is encountered and the depth is reduced by half.

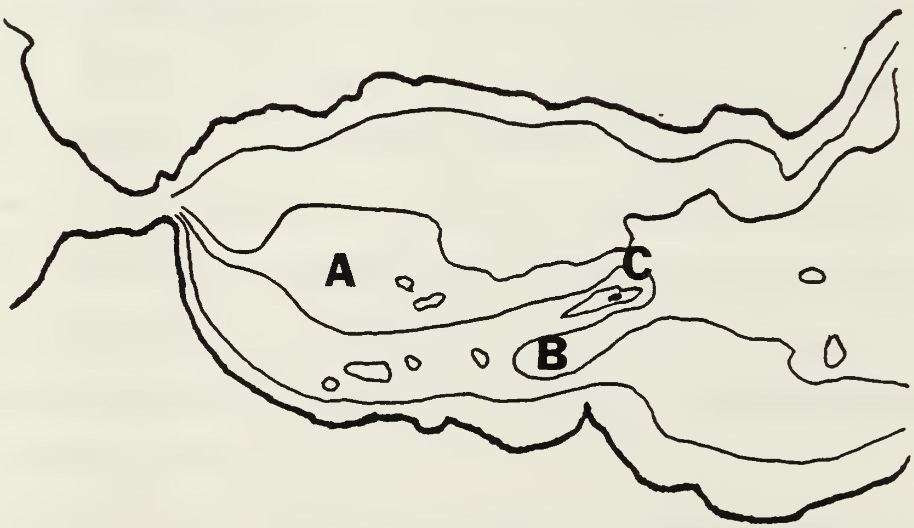

Figure 1 Western Mediterranean Bathymetry Sketch

B. WESTERN MEDITERRANEAN SURFACE CIRCULATION

The predominant circulatory feature here is the Alboran Gyre, position 1 (see Fig. 2). This is formed by relatively cool and less salty North Atlantic water entering through the Strait of Gibralter hugging the Spanish coast until at about 4° West were it splits and a large shallow tongue of it flows south then west at Cape Tres Forcas, i.e., clockwise, to form what is the Alboran Gyre. That part of the inflow which does not flow west turns east and follows the North African coastline as the African Current, position 2.

The Alboran Gyre is an anticyclonic mesoscale oceanographic feature, approximately 80-120 km in diameter, where relatively cool low salinity water surrounds a deeper bowl of warm Mediterranean water [Ref. 8: p. 1 - 1].

Figure 2 Western Mediterranean Surface Circulation Sketch

Some of the North Atlantic water does not flow south to form the gyre, but continues east along the Spanish coast until reaching the eastern Alboran Basin. Near Capo de Gata, most of the rest of this inflow diverts south and becomes known as the Almaria Front, position 3. This jet of relatively cool, low salinity water often separates the Eastern Alboran Basin to the west and the Algerian Basin to the east. Satellite infrared images of the region show this feature consistently.

It is the high rate of evaporation of the Mediterranean, especially in the east, which drives the North Atlantic's inflow or replacement action. Also, as evaporation occurs, the resulting higher salinity water sinks and eventually "seeks its own level." It accomplishes this by flowing west over the sill at Gibralter and out into the North Atlantic; also driving replacement. [Ref. 4: p. 1] Other important forces which impact on the circulation include submarine topography, tidal influence, atmospheric pressure, wind and geostrophic effect [Ref. 9].

III. DATA DESCRIPTION

The data set for this thesis consists of three independently acquired "measurements," the shuttle sun glint images taken on 8 October, AXBT thermal profiles measured on 10 October, and infrared (IR) images from the NOAA-7 AVHRR satellite which span the period.

A. SHUTTLE IMAGES

The extraordinary resolution found in these images is a result of the mechanism which produces sun glint or glitter. Briefly, the sun as an illuminator produces a broad spectrum of radiation including the visible band. The inherent reflectance of the sea surface, the angle of incidence of the radiation, and its wavelength as well as the observers position determine the intensity and conformation of the reflection. The angles of incidence and reflectance of the solar radiation must be similar in order to maximize the effect. As long as the geometry of the sun, sensor, and surface are correct and little or no intervening filters exist, such as clouds or fog, sun glint reflections can provide amazing detail of sea surface structure. Care must be taken in sun glint image analysis, though, because a radical change in brightness polarity can result as one moves in and out of the sun's specular reflection. For instance a very smooth sea surface will appear as a bright patch if it lies within the specular reflection of the sun; under ideal conditions the sun would appear distinctly as a bright ball. Conversely this same surface will appear dark as it is viewed away from the sun's specular reflection. Another important point

is that as a surface is viewed farther away from the specular point steeper angles of reflection are required to produce glitter. In other words, waves with steeper slopes are required to produce an apparent reflection as one moves away from the specular point. This phenomena of glitter has also been observed resulting from lunar illumination [Ref. 1: p. 13]. For a more complete treatise of this subject including the interaction of sea surface temperature and adjacent atmospheric temperature see Reference 2.

The sun glint series studied consisted of images S17 38 79 through S17 38 82. They were taken with a NASA-modified Hasselblad camera equipped with a 250mm. lens using Kodak Ektachrome 64 Professional 5017 (color) film at an altitude of 125 n.m. [Ref. 10]. The first in the series contains Capo de Gata (see Fig. 4) in the upper left hand corner, an easily located geographical reference [Ref. 10: p. A-19]. This image, as well as the others, has at least 12 relic ship wakes which run almost parallel to lines of latitude. Other features such as submesoscale fronts and eddies, and surface film convergences permit the series to be easily and confidently mated to form a continuous, highly detailed picture of a large swath of water. Thus the first problem of locating this record geographically is relatively easy, but to digitally correct it to a Mercator projection is extremely difficult and unreliable since only one small corner of the composite image has land which can be used as a reference in a registering process; and although the shuttle's nadir position is known the angle of the camera's lens relative to the field of view was not recorded. The camera was hand held. All four images have a resolution of less than a kilometer.

B. SUN GLINT IMAGE ANALYSIS

In spite of the obvious lack of hard quantitative scaling and positional data for the sun glint series, some improvement in analysis was accomplished. The nadir position of the shuttle was known to within six minutes of a degree for each time an image was taken [Ref. 10: p. A-2]. The shuttle's altitude of 125 n.m. and the direction of the field of view from the shuttle was also known [Ref. 10: p. A-19]. In frame 79 the geographical reference point Capo de Gata is visible (see Fig. 4). By plotting its position and the nadir position of the shuttle at the time the photograph was taken on a navigational chart, a distance of 128 n.m. was measured between the two points. By computing the arc tangent of 128 n.m./125 n.m. a tilt angle of 45.7° was approximated for the camera lens. Two simplifications were made. Earth curvature was ignored and the reference point used, Capo de Gata, was not the center point of the image. By expanding and contracting the distance entered in the calculation, i.e., to assess error, a plus or minus 2° accuracy was assigned to the tilt angle result. The 45.7° tilt angle compares favorably, with respect to sun glint opportunity, with the recorded sun elevation angle of 41° at shuttle nadir for this series of images [Ref. 10: p. A-19]. Tilt angle and mission altitude are the entering arguments for a ground distance nomogram provided by the SHUTTLE EARTH OBSERVATION PROJECT Johnson Space Center. The result from the nomogram which is specific for the Hasselblad 250 m.m. lens was a ground distance parallel to orbit track of forty n.m., with an error of plus or minus 2 n.m. based on the previously computed tilt angle error.

An assumption can be made that the vertical edges of the sun glint images, as mounted in this work, are parallel to the orbit track. This is supported by alignment of the images to Capo de Gata and the shuttle's orbit plotted on a navigational chart (see Fig. 3) [Ref 11]. This results in each inch on the photograph being equivalent to 5.3 n.m. in the vertical. A second nomogram was entered for the scaling in the direction along the principal line of view for the image or perpendicular to the orbital track. This was also supplied by the Johnson Space Center. Scaling in the horizontal direction was computed to be 6.7 n.m. per inch. Since the series, when mated to form a mosaic, resolves a swath of water in a pattern similar to the shuttle ground track and since all four images were taken in a fifteen second interval it is reasonable to assume that the photographic geometry was nearly the same for every image in the series. Additionally, the sun's specular reflection is evident on three of the four sun glint images. Hence, tilt angle of the camera lens must be nearly equal to the sun's angle of incidence. Since the field of view is displaced 128 n.m southwest of the shuttle nadir, the tilt angle must be somewhat greater than 41°. The computed tilt angle of 45.7° is then consistent with the record. The accuracy of the scaling was substantiated by comparing the extreme dimension of the land mass, as determined from the scales on Figure 4, with its charted dimension and close agreement, within one n.m., was found.

Frame 79 was taken at 13:12:52 Greenwich Mean Time (GMT) or one hour before local apparent noon. The frame's center right is dominated by

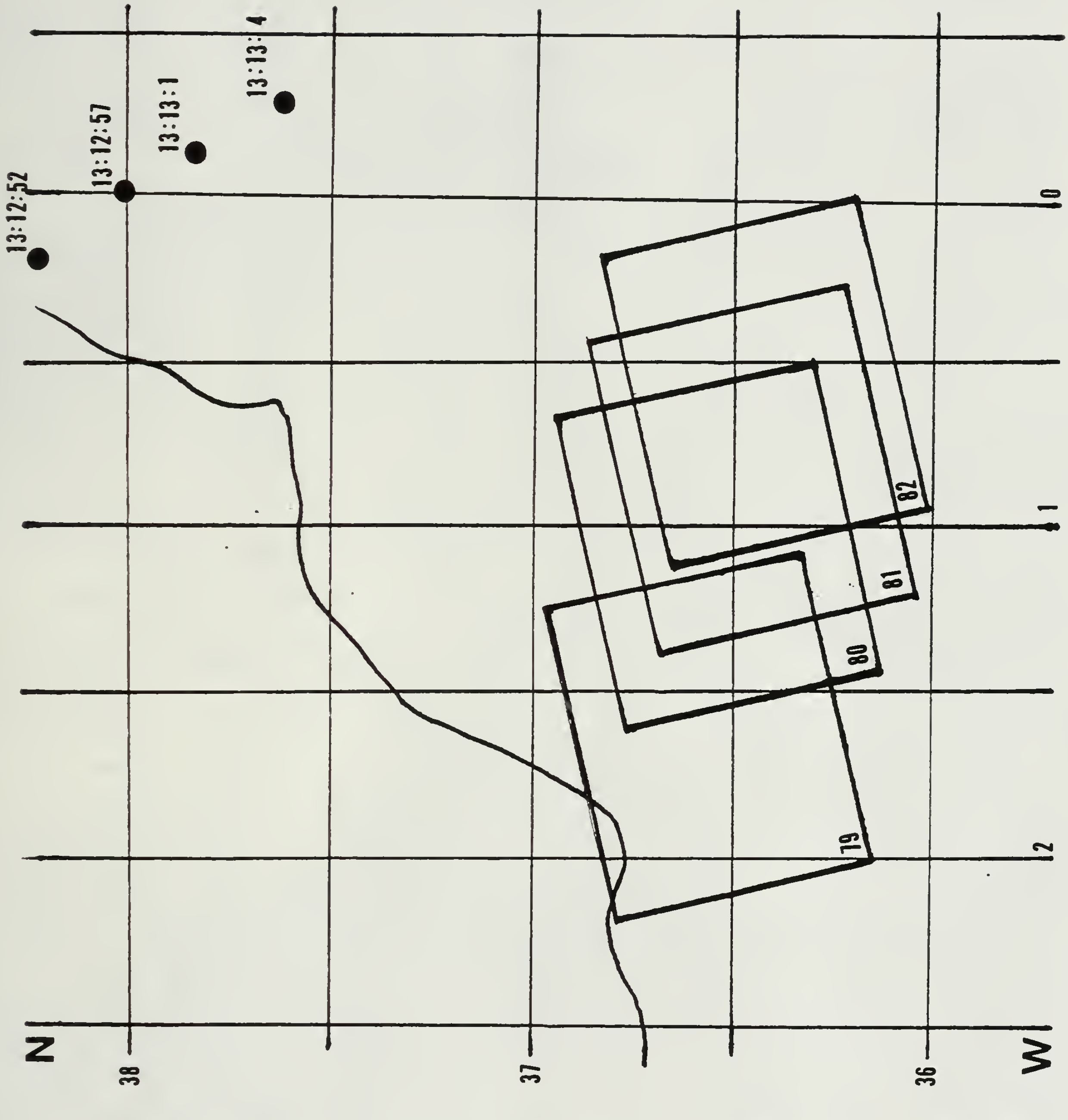

Figure 3 Shuttle Ground Track and Image "Footprints"

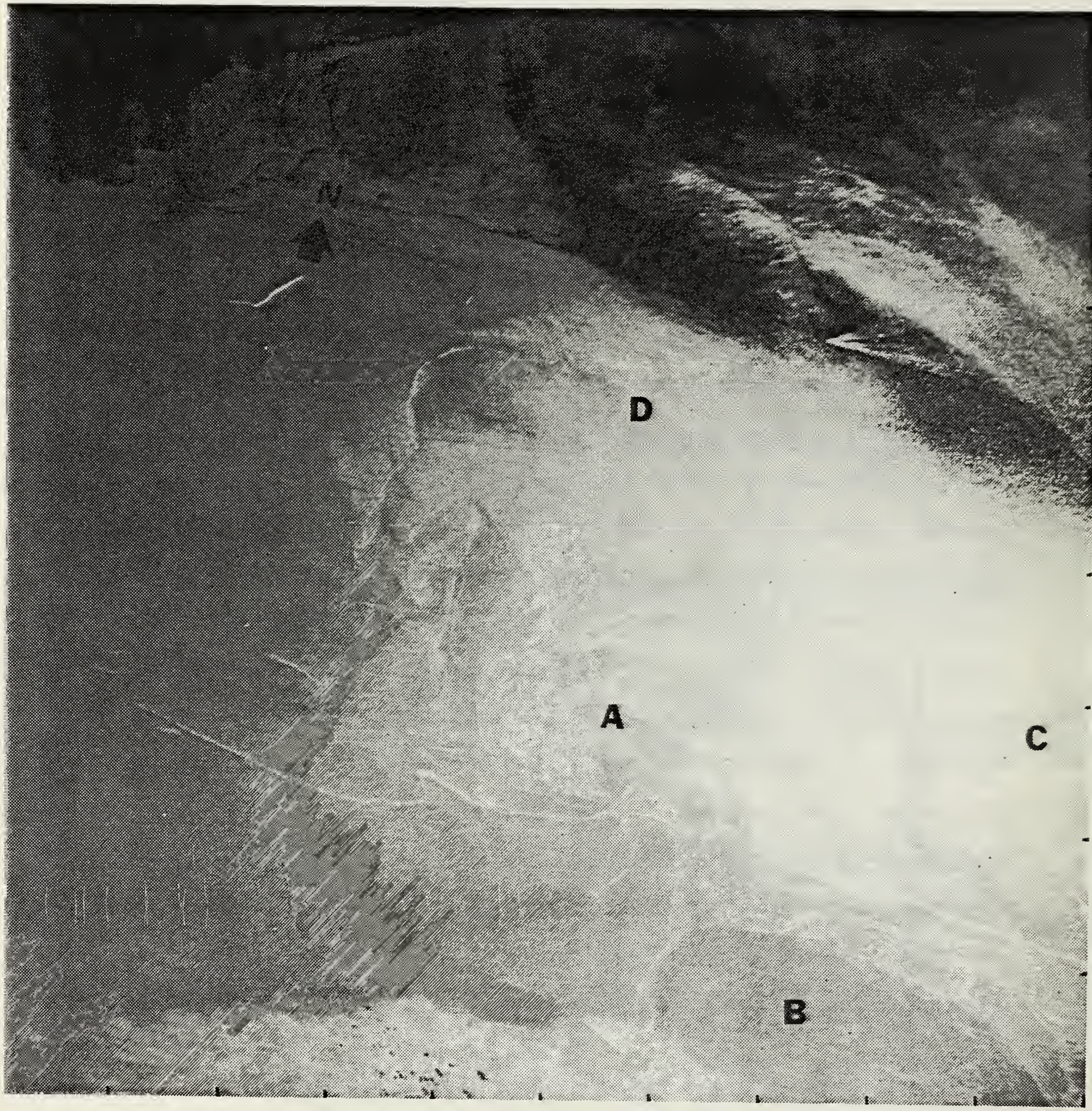

Figure 4 STS 41-G Sun Glint Image S17-38-79 8 Oct. 1984 13:12:52 GMT

the sun's specular reflection (see Fig. 4). In the upper left hand corner Spain's Capo de Gata is seen with some internal waves apparent just off the coast.

The upper right hand corner is characterized by large blue regions which indicates a paucity of waves with the correct slopes to reflect the sun as glitter. This conclusion is also supported by the extraordinary ship's Kelvin wake seen in this part of the image. The interaction of the wake with the local wave pattern has resulted in favorable sun and wave slope presentations. Farther south, a textural change is apparent on the sea surface indicating a change in specular reflectance intensity of this part of the sea. The most imposing oceanographic feature of frame 79 is the cyclonic submesoscale gyre, position A, centered approximately thirty n.m. southeast of Capo de Gata; ship's wakes and surface film convergence patterns enhance its visualization. Across most of the southern edge of the photograph a textural discontinuity is evident. Position B exhibits a different texture, from water north and south, and may represent a relative change in water characteristics. Although not well imaged in this frame a small, perhaps five km. in diameter, cyclonic eddie exists at position C. Three ship wakes, important for the unambiguous joining of the frames, are aligned in a southwest to northeast line and are marked by position D.

Frame 80 was taken five seconds later and provides a slightly different view of one third of frame 79 as well as containing new area (see Fig. 5). Here the calm sea conditions present in the first image are confirmed and the existence of another cyclonic

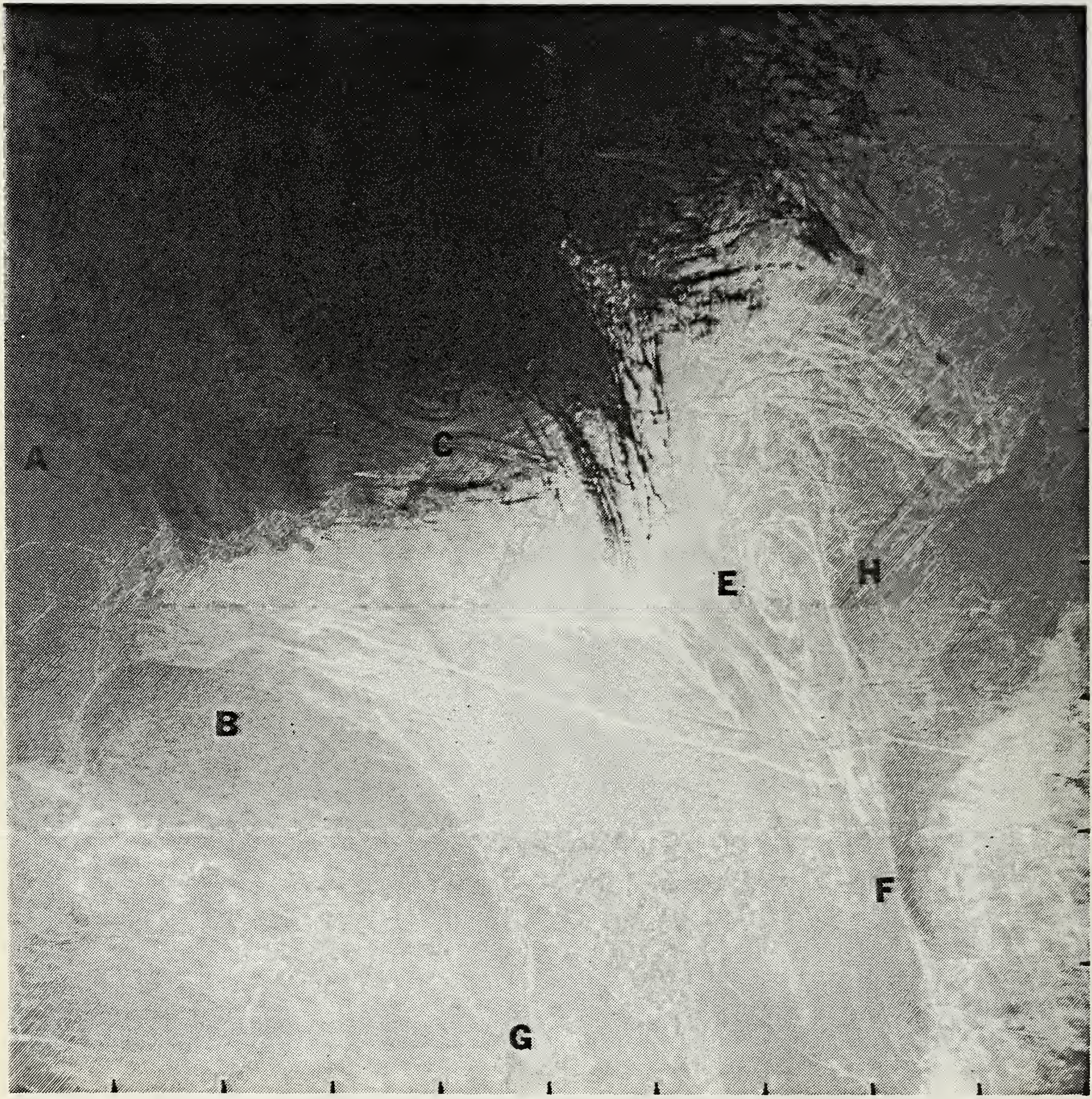

Figure 5 STS 41-G Sun Glint Image S17-38-80 8 Oct. 1984 13:12:57 GMT

submesoscale eddie centered thirty-five n.m. east of the frame 79's is seen, position E. This image contains all of the features designated in the previous frame. Position F, approximately seventy n.m. east southeast of Capo de Gata marks a frontal boundary and shear zone. The lateral displacement of the wakes and slick patterns across the front coupled with the cyclonic submesoscale eddy, position E, infer that a relative movement has occured there. This shear zone then is a result of water mass flow in a north south direction. Position G marks another cyclonic eddie which appears to be part of a series of eddies aligned along a northwest to southeast line. Position H may mark a different water mass from that which lies to the west. The surface texture change here may be the result of a relative difference in adjacent atmosphere and sea surface temperatures.

Frame 81, although covering no unique area, serves to connect frames 80 and 82 and provides a different view of some of the features in those images (see Fig. 6). The water mass marked as B on frames 79 and 80 is seen as well as the eddies E and G, The large frontal shear zone, positions F and H, as seen on frame 80 is seen here in more detail and its importance, at least in size, is confirmed. The sun's specular reflection is centered on the lower right edge of the photograph, position I, and illuminates a triangular region of the image. East of position H the sea surface exhibits "tufting," a discontinuous sun glint pattern. This may be the result of atmospheric forcing, i.e., wind, driven by a relative low atmospheric pressure over warmer water on the right side of the image marked by position J, or turbulent mixing associated with the marine boundary layer. This would result from the

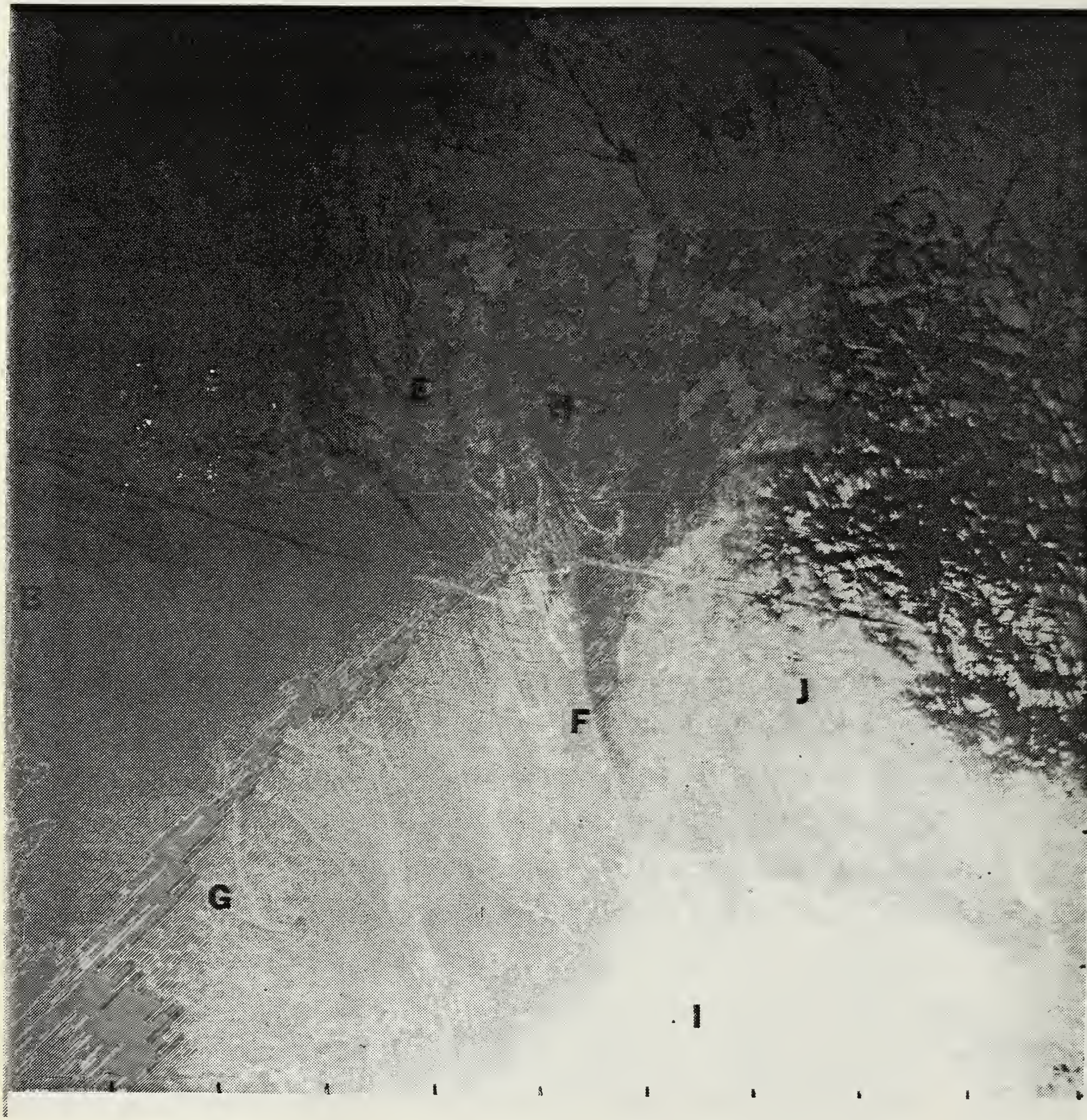

Figure 6 STS 41-G Sun Glint Image S17-38-81 8 Oct. 1984 13:13:1 GMT

surface water temperature being in excess of the overlying air temperature.

The final image , frame 82, substantiates the indications of the previous one and essentially shows what appears to be a front on its lower half, position I (see Fig. 7). The frontal shear zone which is also indicated on frames 80 and 81 and runs essentially in a north south direction, positions F and H, has a location and alignment that suggests the Almaria front. Its location, as measured from the photos overlayed as a mosaic, is approximately seventy n.m. east southeast of Capo de Gata. The "tufting" patt^rn noted on frame 81 is shown to be a large and homogeneous surface field, position J.

As with all of these images many more features exist but an investigation of their individual importance exceeds the scope of this work.

C. NOAA-7 AVHRR INFRARED IMAGES

Five NOAA-7 AVHRR infrared images were used in the study. The October 7 image clearly shows the Almaria front, position B, which is seen as a north south aligned, cooler region of water with some submesoscale eddies formed along its length (see Fig. 8). The front is displaced a little to the east of Capo de Gata. On either side of this feature warmer surface temperatures are recorded. This cool jet is seen to have a flow pattern which reaches all the way to the North African coast. The Alboran Gyre is also very evident east of Gibralter, position A. The resolution for the NOAA-7 images is approximately 1 kilometer at nadir and in this data set they are registered to a Mercator projection.

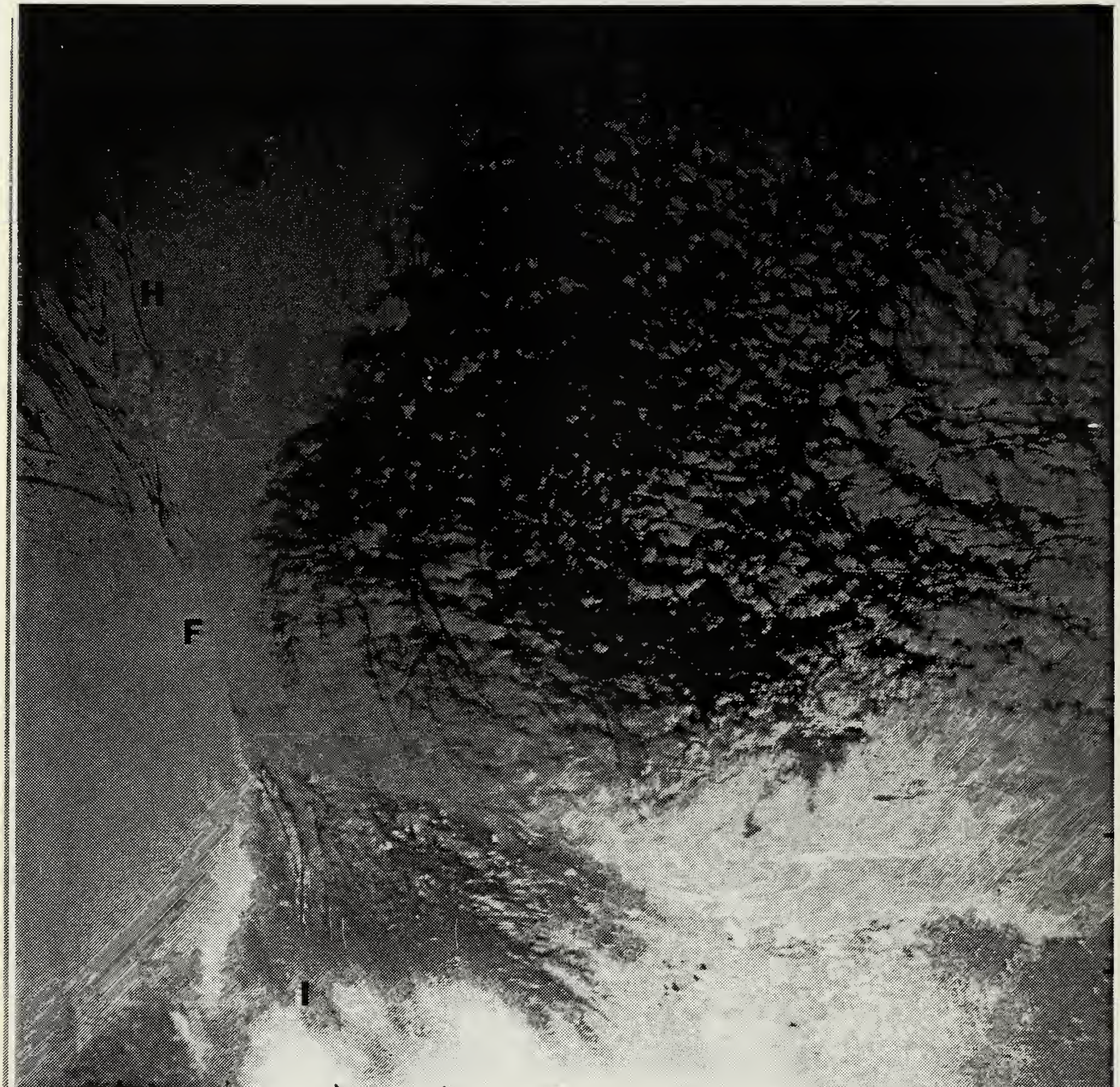

Figure 7 41-G Sun Glint Image S17-38-82 8 Oct. 1984 13:13:5 GMT

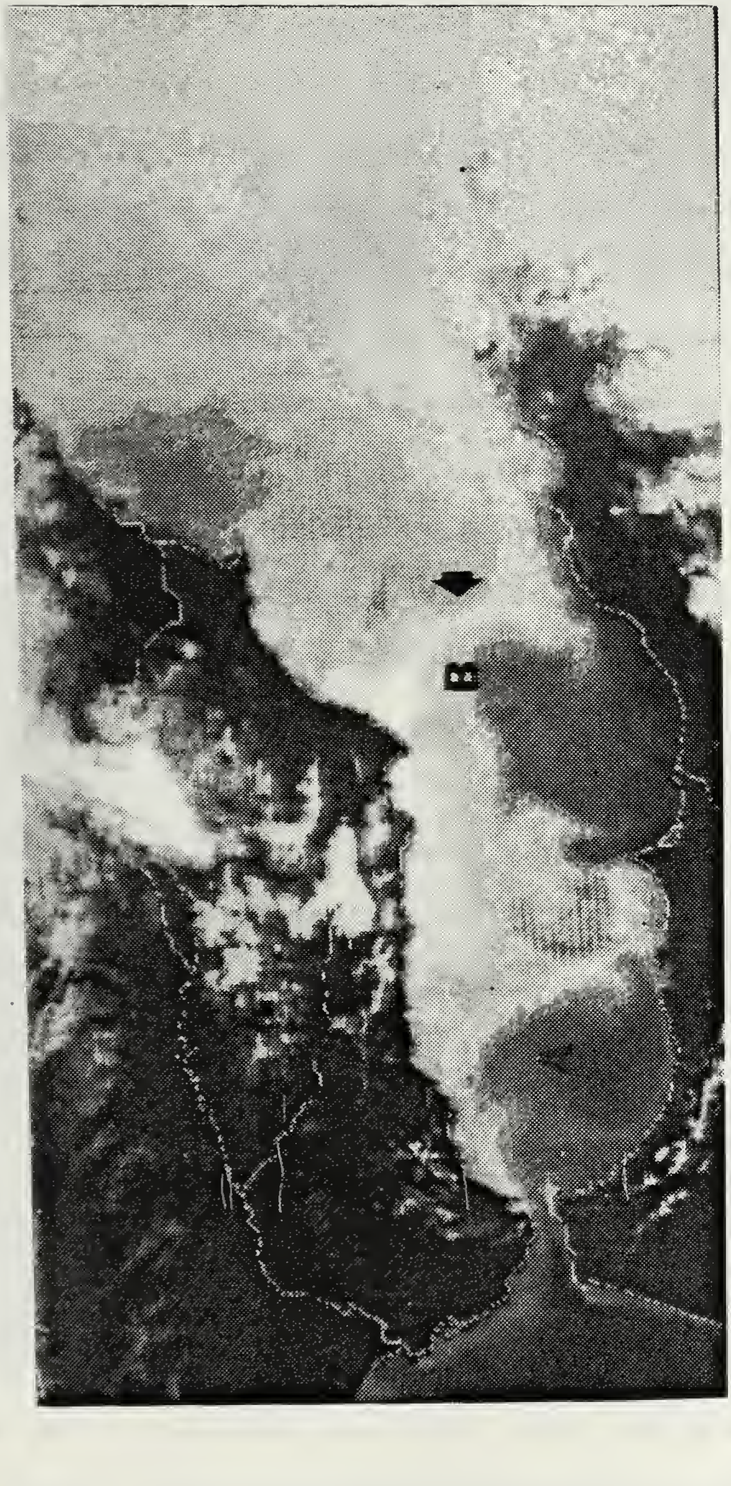

Figure 8 NOAA-7 AVHRR IR Western Mediterranean 7 Oct. 1984

On 8 October high, thin cirrus clouds prevented useful infrared imaging of the sea surface (see Fig. 9). Interestingly though, the shuttle images, taken in the visible band, do not show this; they appear very clear. In fact Mr. Power's flight notes indicate that the Mediterranean was free of clouds in this area at this time [Ref. 12].

The 9 October image only resolves the Alboran Gyre, position A. Heavy clouding to the east prevented the Almaria Frontal region's surface temperature signal to be registered (see Fig. 10). The Alboran Gyre is clearly seen but temperature gradients across it seem to very less than on the 7 October image.

The 10 October infrared image indicates a well defined Alboran Gyre, position A, (see Fig. 11). Cool Atlantic water seems to hug the Spanish Coast and the Almaria Front, position B, is displaced to the east as on the 7 October image. By using the geographical reference points superimposed on the image, a temperature discontinuity is evident seventy n.m. east southeast of Capo de Gata, position F. Its position and conformation match the frontal shear zone marked by positions F and H on the sun glint images. The greatest grey shade difference on the IR image in this region represents a variation in sea surface temperatures between seventeen and twenty-two degrees Celcius as reported from ships in the area. Some clouds are evident in the extreme right hand side of the image and their existence and extent are confirmed in the NOAA-7 channel 2 visible image of the area.

On 11 October the entire Alboran Sea was clear of any significant cloud cover (see Fig. 12). This image shows all of the oceanographic features previously discussed including the Almaria Front. Comparing

Figure 9 NOAA-7 AVHRR IR Western Mediterranean with Cirrus Clouds 8 Oct. 1984

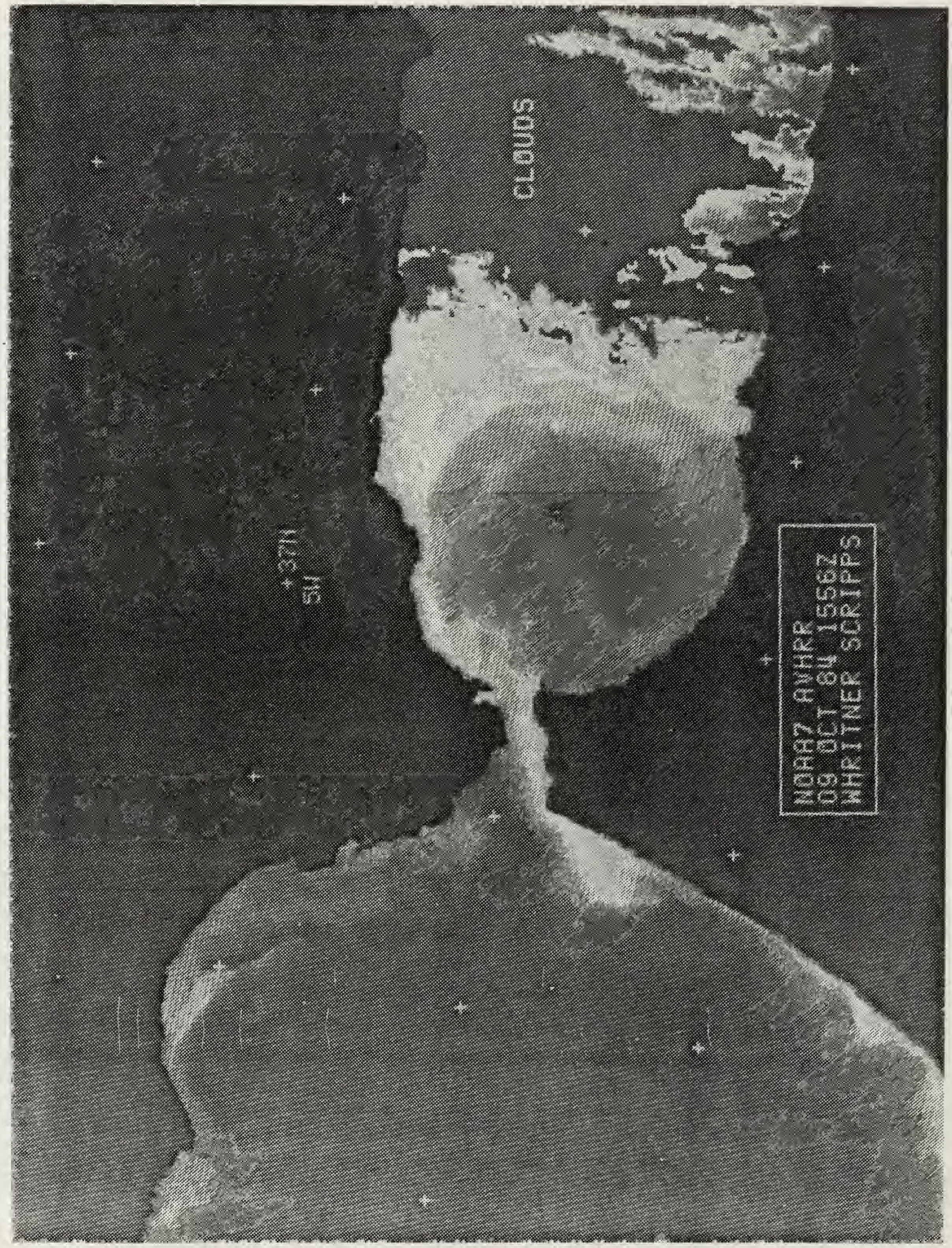

Figure 10 Western Mediterranean IR
with Cloud Blocked Areas Removed

Figure 11 Western Mediterranean IR with Arrow Indicating Frontal Shear Zone

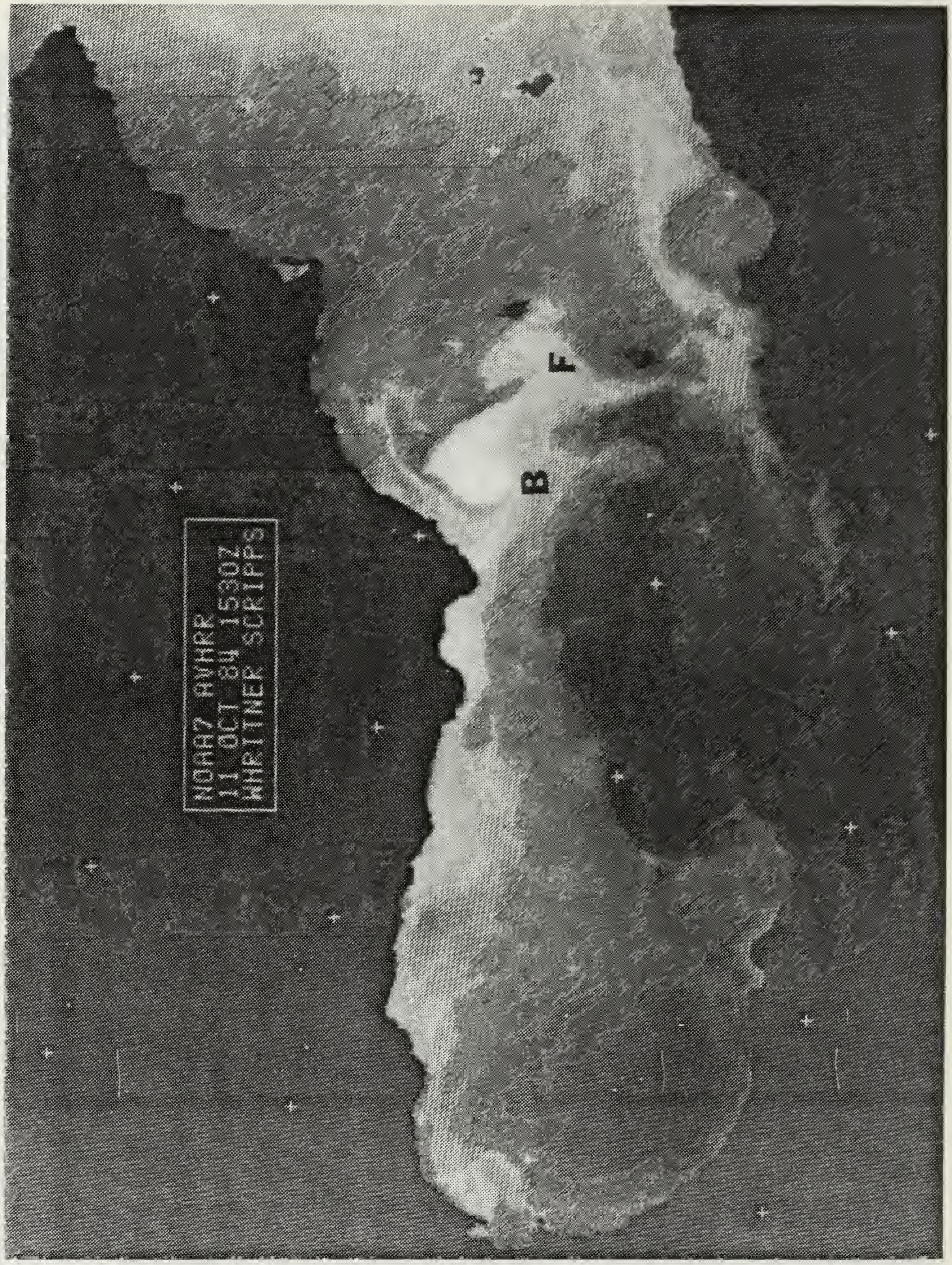

Figure 12 Western Mediterranean IR
with Arrow Indicating Frontal Shear Zone

this image with 7 October's we see the Almaria Front to be much broader in its east to west extent. It is also interesting to see how it has changed from the previous day of 10 October. However the temperature discontinuity located seventy n.m. east southeast of Capo de Gata is still evident, position F.

D. AXBT THERMAL PROFILING

On 10 October forty-nine AXBTs buoys were placed across the Almaria Front using a U.S. Navy P-3C antisubmarine warfare (ASW) aircraft. The geographical locations of the buoys were fixed using the aircraft's onboard tactical navigation system, which has a nominal radial accuracy of one n.m. Location of the surface manifestation of the front was determined from the aircraft using Forward Looking Infrared or FLIR. Two, essentially parallel, lines of buoys where dropped at ten n.m. intervals between the buoys and approximately fifteen n.m. between the lines. The pattern was aligned in a southwest to northeast direction which is perpendicular to the Almaria Front (see Fig. 13). By plotting depths of specific temperatures against their geographical position, i.e., transects, it is possible to determine if any temperature discontinuities exist at the resolution afforded by the buoy separation (see Fig. 14). Comparing Figures 13 and 14 clearly illustrates that a temperature fine structure does exist at this level of resolution.

Buoys one through seven indicate a dramatic decrease in the depth of the seasonal thermocline and loss of the mixed layer. Buoys eight through nineteen essentially maintain the same seasonal thermocline depth, however some fine structural dynamics are apparent near the surface; perhaps resulting from interleaving of mixed watermasses at a

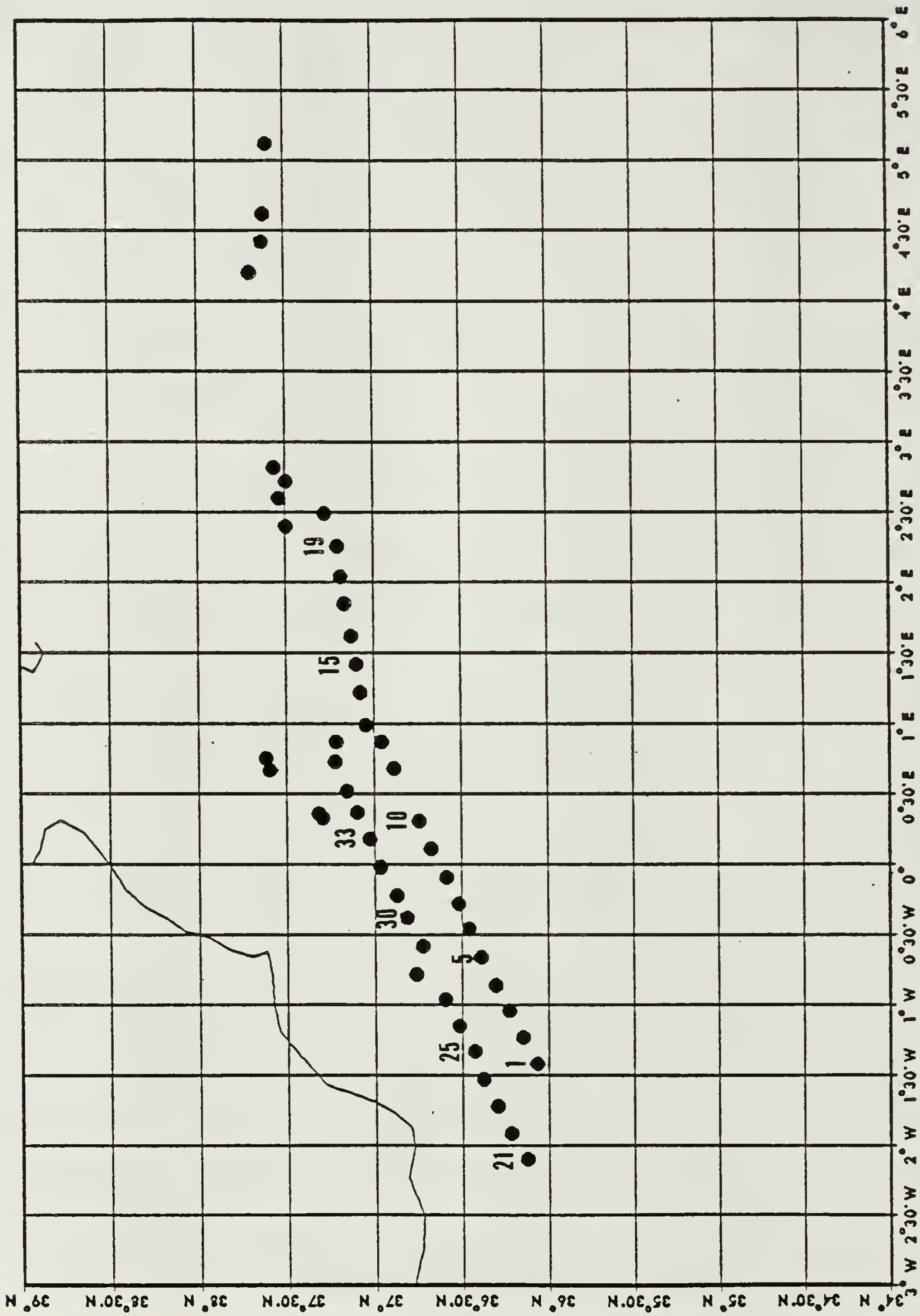

Figure 13 AXBT Positions

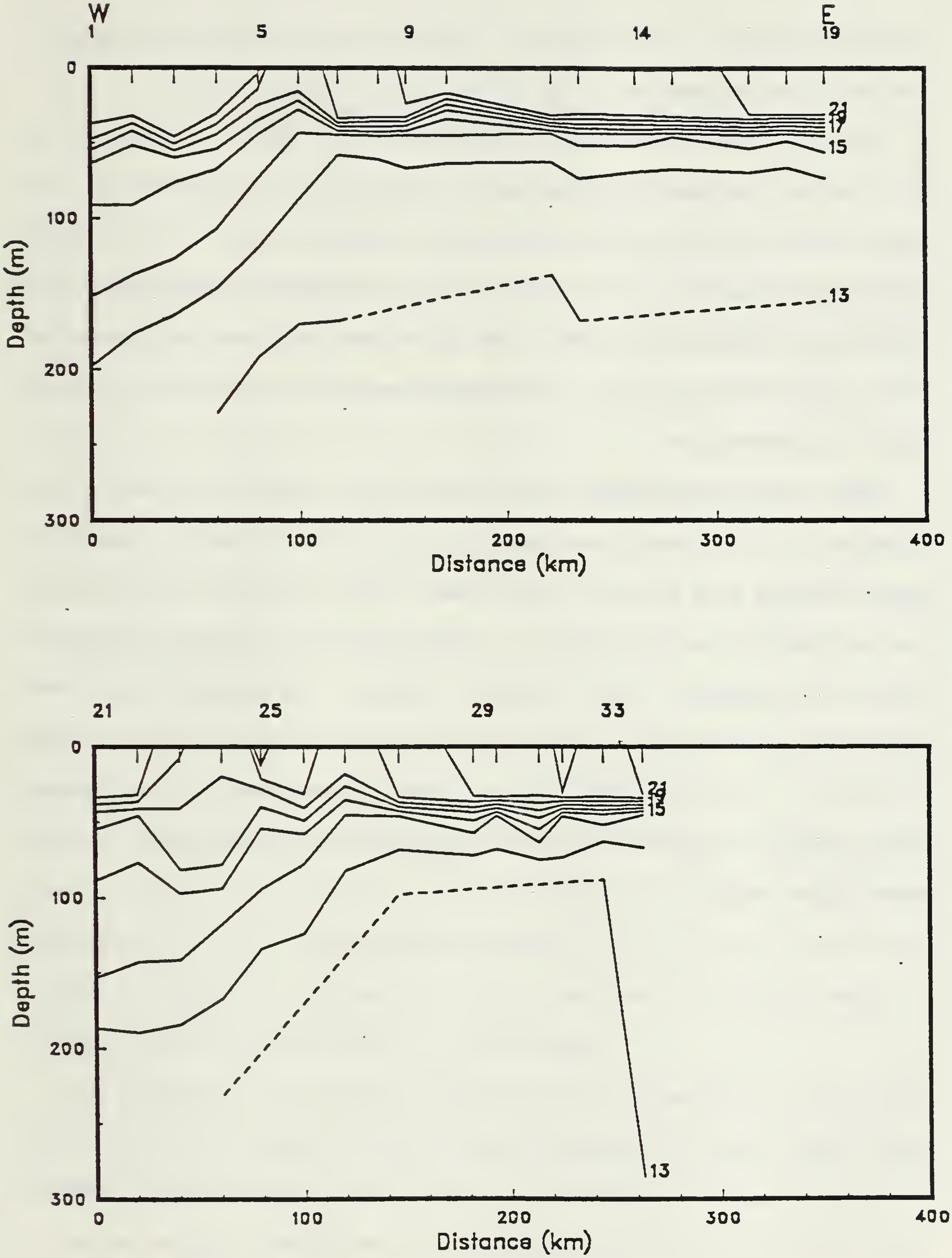

Figure 14 AXBT Temperature Transects

frontal boundary. Buoys nine and seventeen also mark reestablishment of the depth and temperature of the mixed layer of the region.

Buoys twenty-three through twenty-seven also exhibit a decrease in the seasonal thermocline in much the same way as what appeared in the more southerly buoy line with the exception that it is skewed approximately ten n.m. to the west. The rest of the record indicates a relatively homogeneous water mass to the east with a mixed layer of about forty meters in depth and between twenty and twenty-one degrees Celsius in temperature.

Three of the thirty-four buoys used in the study were assumed to be anomalous. If a buoy's profile differed radically from its neighbors and the other data sets did not support such a departure then that buoy was not included in the transect. Additionally if an individual buoy's temperature verses depth profile showed anomalous temperature fluctuations indicative of wire breaks or insulation leakage it was discarded. The other AXBTs deployed on 10 October were too far removed from the area resolved by the sun glint images to be useful in this correlation study.

IV. WIND, WAVE, AND CLOUD REPORTS FOR THE AREA

The following was extracted from archival data provided by the Fleet Numerical Oceanographic Center Monterey, California. It was used to help substantiate the surface conditions of the area imaged. At midnight Greenwich Mean Time (GMT) on 8 October the winds south of Capo de Gata were from the north to northeast at ten to fifteen knots. Reports from ships in the area indicate clear to scattered cloud cover, seas calm to one meter in height and sea surface temperatures (SST) in the twenty degree Celsius range. No significant atmospheric disturbances were recorded. It is important to note that one ship in the region recorded an SST of seventeen degrees. At 1200 GMT on the same day the wind pattern was little changed, however a few hours later reports of increasing cloudiness were recorded. SSTs reported ranged between seventeen and twenty-two degrees.

At midnight GMT 9 October winds were northeasterly to easterly and had subsided to ten knots. Area ship reports indicated cloud cover increasing to 5/8 coverage with wave heights of one meter. By 1200 GMT cloud coverage had increased to 6/8 in the area with little change in reported wind direction, speed or wave height.

At midnight GMT 10 October ships in the area reported 2/8 to 6/8 cloud cover with winds from the north northeast at 8 to 17 knots. Wave heights were reported at one meter. By 1200 GMT most ships in the area reported reduced clouding of 2/8 coverage. The SSTs reported also showed a wide variation even for closely located ships.

V. RESULTS AND CONCLUSIONS

A. CORRELATION OF DATA

The north-south aligned frontal feature, marked as H and F on Figures 5, 6, 7 match very closely in position and character the Almaria Front imaged by NOAA-7 on 7 October (Fig. 8). Both are in the same geographical position, seventy n.m. east southeast of Capo de Gata, and their conformation which runs linearly north to south is similar.

Although the NOAA-7 infrared image taken on 10 October, Figure 11, is temporally separated from the shuttle images, by two days, it is important in establishing the validity of using the infrared as "ground truth" and to connect the 7 October infrared image with the 8 October shuttle images. The position of the front on 10 October as determined by the AXBTs match very closely its position on the infrared image taken on the same day. Figure 15 is an area enlargement of the 10 October IR image with the AXBT positions superimposed on it. By comparing Figures 14 and 15 a good correlation of this data set results. Additionally this feature is in the same positon as the frontal shear zone in the sun glint record (Figs. 5,6, and 7). The Almaria Front, as imaged by NOAA-7 on 10 October, is located at the same place as on the 7 October NOAA-7 image. The details of the circulation around the front have changed but the general location of it has not.

Based on the Almaria Front's location on 7 October and its persistence at the same location on 10 October, it is reasonable to extrapolate for it being in the same location on 8 October the day of

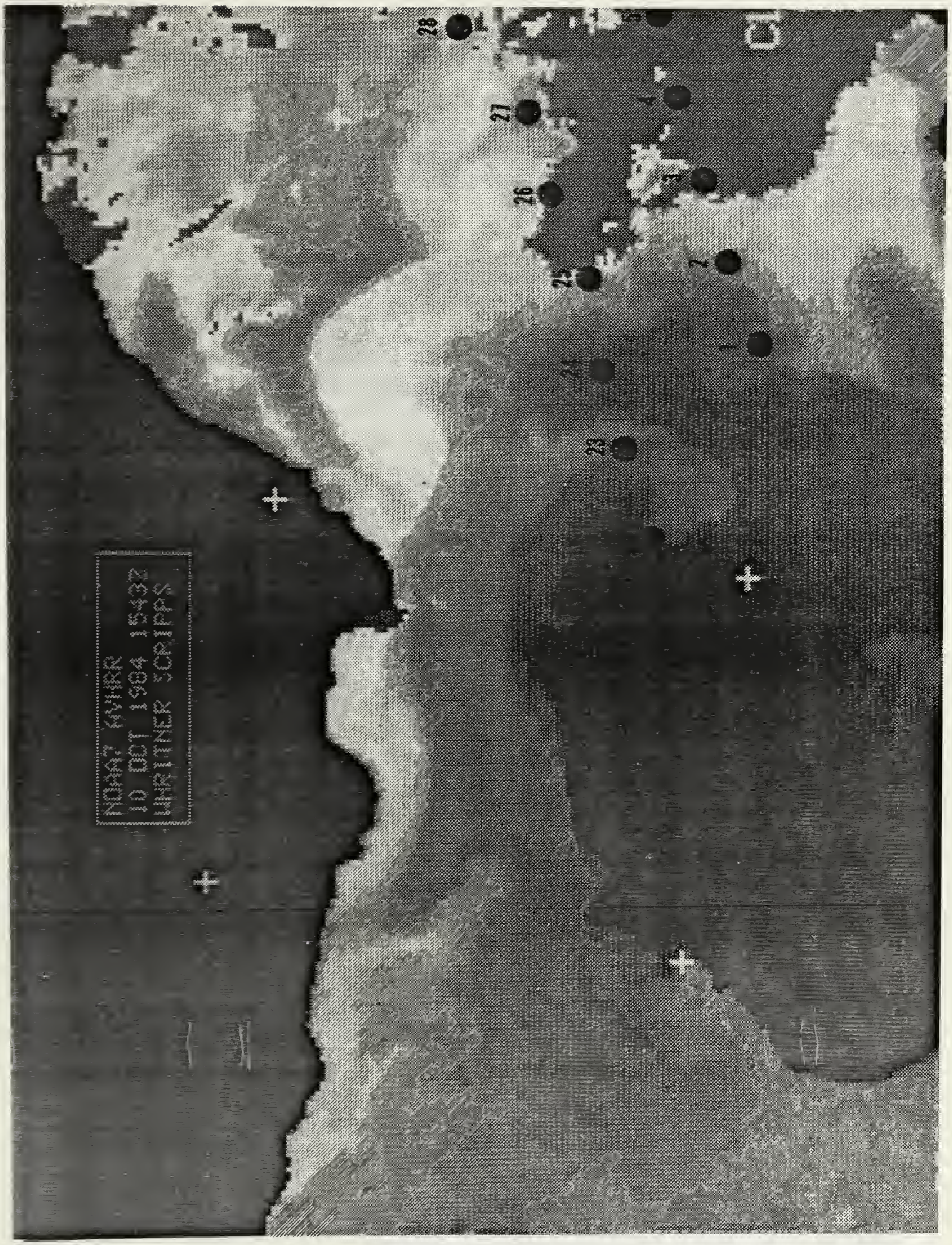

Figure 15 10 Oct. 1984 IR Image of Almaria Front
with AXBT Positions Overlayed

the shuttle sun glint pictures. Careful analysis of the sun glint series results in concluding that there is only one vertical front imaged and its position correlates very well with the front in the infrared images of NOAA-7.

B. CONCLUSION

Sun glint images can be used to accurately position and characterize the surface manifestation of oceanic frontal boundaries. In this case the frontal boundary included a significant change in both the mixed layer and seasonal thermocline. The data correlated well, within the limitations imposed by the analysis. As a result, these sun glint images could have been used to infer directly that an acoustically important discontinuity existed at the position of the frontal shear zone recorded on the shuttle sun glint images.

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